



PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re the Application of:

Olli PIIRAINEN et al.

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Application No.: 10/627,962

Examiner: not yet assigned

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For: PAR REDUCTION FOR EDGE CLIPPER

CLAIM FOR PRIORITY UNDER 35 USC § 119

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

June 18, 2004

Sir:

The benefit of the filing dates of the following prior foreign application filed in the following foreign country is hereby requested for the above-identified patent application and the priority provided in 35 U.S.C. §119 is hereby claimed:

Great Britain Patent Application No. 0312213.2 filed on May 28, 2003 in Great Britain

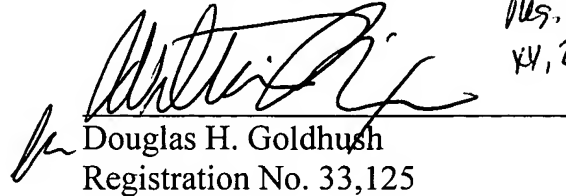
In support of this claim, certified copy of said original foreign application is filed herewith.

It is requested that the file of this application be marked to indicate that the requirements of 35 U.S.C. §119 have been fulfilled and that the Patent and Trademark Office kindly acknowledge receipt of this document.

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Enclosure: Priority Document (1)

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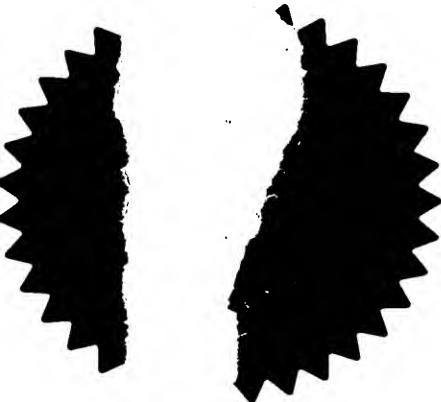
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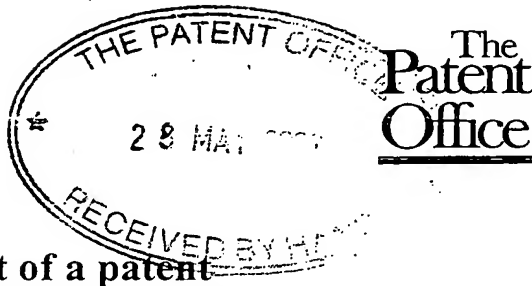
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Signed *Stephen Handley*
Dated 17 May 2004

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Request for grant of a patent

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1. Your reference 302471GB/DJW/ac

2. Patent application number 0312213.2
(The Patent Office will fill in this part)

3. Full name, address and postcode of the or of each applicant (underline all surnames) NOKIA CORPORATION
KEILALAHDENTIE 4
02150 ESPOO
FINLAND

Patents ADP number (if you know it)

7652217004

If the applicant is a corporate body, give the country/state of its incorporation

FINLAND

4. Title of the invention PAR REDUCTION FOR EDGE CLIPPER

5. Name of your agent (if you have one) PAGE WHITE & FARRER
"Address for service" in the United Kingdom 54 DOUGHTY STREET
to which all correspondence should be sent LONDON
(including the postcode) WC1N 2LS
UNITED KINGDOM

Patents ADP number (if you know it)

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6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and (if you know it) the or each application number	Country	Priority application number (if you know it)	Date of filing (day / month / year)
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7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application	Date of filing (day / month / year)
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8. Is a statement of inventorship and of right to grant of a patent required in support of this request? (Answer 'Yes' if:

a) any applicant named in part 3 is not an inventor, or

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See note (d)) YES

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Description 12

Claim(s) 3

Abstract 1 *DL*

Drawing(s) 3 *13*

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Priority documents

Translations of priority documents

Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77)

Request for substantive examination (Patents Form 10/77)

Any other documents
(please specify)

11. I/We request the grant of a patent on the basis of this application.

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PAGE WHITE & FARRER 28 May 2003
David J Williams 020 7831 7929

12. Name and daytime telephone number of person to contact in the United Kingdom

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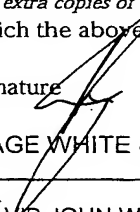


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**Statement of inventorship and of
right to grant of a patent**

The Patent Office

Cardiff Road
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1. Your reference	302471GB/DJW/DG/SJW
2. Patent application number (if you know it)	0312213.2
3. Full name of the or of each applicant	NOKIA CORPORATION
4. Title of the invention	PAR REDUCTION FOR EDGE CLIPPER
5. State how the applicant(s) derived the right from the inventor(s) to be granted a patent	By contract of employment
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7.	I/We believe that the person(s) named over the page (and on any extra copies of this form) is/are the inventor(s) of the invention which the above patent application relates to. Signature  Date 11 May 2004 PAGE WHITE & FARRER 8. Name and daytime telephone number of person to contact in the United Kingdom
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PAR REDUCTION FOR EDGE CLIPPER

Field of the Invention

The present invention relates to the reduction of the peak-to-mean average amplitude in a signal transmitted in a power amplifier, and particularly but not exclusively to such reduction in the power amplifier of a multicarrier communication system utilising an EDGE clipper.

Background to the Invention

Mobile communication systems, such as enhanced data rates for GSM (Global System for Mobile communications) evolution (EDGE) systems, utilize a power amplifier in a transmitter at the base transceiver station for transmitting signals.

It is known that a signal with a high peak-to-mean (average) ratio (PAR) sets high requirements for power amplifier linearity, and therefore reduces achievable power efficiency and increases the power consumption of the power amplifier. In order to improve efficiency, algorithms are utilised to reduce the peak-to-mean ratio of a transmitted EDGE signal. Nevertheless, system requirements set limits for achievable PAR reduction. The main transmission requirements are the signal frequency, peak EVM (Error Vector Magnitude) amplitude, and RMS (Root Mean Square) EVM.

Clipping algorithms provide one method to reduce the PAR, but at the cost of increasing the Error Vector Magnitude (EVM) of the transmitted signal. Different clipping algorithms have been previously studied in the case of WCDMA (Wideband Code Division Multiple Access) signals, and as a result some algorithms have been proposed for implementation. In the case of multicarrier EDGE signaling, the topic of clipping has been specifically studied.

The challenge is to minimize the PAR, but preferably without compromising the frequency requirement, peak EVM requirement, and RMS EVM requirement of the transmitted signal.

There has been ongoing discussion about different methods to minimise peak-to-average ratio (PAR) in EDGE transmissions. Minimising PAR in EDGE enhances the achievable efficiency of the power amplifier. However in known suggested solutions the time-domain properties of the PAR reduced signal can be quite rapidly deteriorated.

It is an aim of the present invention to provide an improved technique which addresses one or more of the above-stated problems.

Summary of the Invention

According to the present invention, there is provided a method of reducing the peak-to-mean ratio of a multi-carrier signal comprising the steps of: generating a residual signal from the multicarrier signal, the residual signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal; applying a least squares function to the residual signal for each carrier of the multi-carrier signal, thereby generating a minimised residual signal for each carrier; and combining the minimised residual signals and the multicarrier signal.

The method may further comprise the step of, prior to the step of combining the minimised residual signals, of filtering each minimised residual signal.

The method may further comprise the step of delaying the multicarrier signal, wherein the delayed multicarrier signal is combined with the minimised residual signals.

The step of generating the residual signal may include a step of clipping the multicarrier signal to a predetermined level to thereby generate the hard-clipped multicarrier signal.

The step of filtering may comprise complex filtering. The step of filtering may comprise a step of multiplying the residual signal by a projection matrix of each carrier's spanned signal space. The step of filtering may include the steps of applying to the residual signal, for each carrier, a matrix function, a sampling function, a filtering function and an interpolation function.

The method may be applied in a mobile communication system.

In a further aspect the present invention provides an apparatus for reducing the peak-to-mean ratio of a multi-carrier signal including: means for generating a residual signal from the multicarrier signal, the residual signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal; means for applying a least squares function to the residual signal for each carrier of the multi-carrier signal, thereby generating a minimised residual signal for each carrier; and means for combining the minimised residual signals and the multicarrier signal.

- 10 The apparatus may further comprise means for filtering each minimised residual signal prior to combining.

The apparatus may further comprise means for delaying the multicarrier signal, wherein the delayed multicarrier signal is combined with the minimised residual signals.

- 15 The means for generating the residual signal may include means for clipping the multicarrier signal to a predetermined level to thereby generate the hard-clipped multicarrier signal.

- The means for filtering may comprise a complex filter. The means for filtering may comprise means for multiplying the residual signal by a projection matrix of each carrier's spanned signal space.
- 20

The means for filtering may include means for applying to the residual signal, for each carrier, a matrix function, a sampling function, a filtering function and an interpolation function.

- In a further aspect the present invention provides a mobile communication system including a transmitter apparatus adapted for reducing the peak-to-mean ratio of a multi-carrier signal including: means for generating a residual signal from the multicarrier signal, the residual signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal; means for applying a least squares function to the residual signal for each carrier of the multi-carrier signal,
- 25

thereby generating a minimised residual signal for each carrier; and means for combining the minimised residual signals and the multicarrier signal.

The mobile communication system may be a GSM EDGE mobile communication system.

5 Brief Description of the Drawings

The invention is described herein by way of reference to the accompanying drawings in which:

Figure 1 illustrates an example implementation of an embodiment of the present invention;

10 Figure 2 illustrates an example implementation of part of the implementation of Figure 1;

Figure 3 illustrates an example implementation of part of the implementation of Figure 1;

15 Figure 4 illustrates an alternative example implementation of an embodiment of the present invention; and

Figure 5 illustrates an alternative example implementation of part of the implementation of Figure 4.

Description of Preferred Embodiments

20 The present invention is described herein by way of reference to preferred embodiments. The invention is described, in particular, by way of reference to an implementation comprising a power amplifier in a multicarrier EDGE system. In the described embodiments, a system having four carriers is illustrated. The invention may, however, apply to multicarrier systems having any number of carriers.

25 A system model is first considered. A signal under evaluation can be modeled as a complex envelope, as follows:

$$y(t) = \sum_{i=1}^{no_of_carriers} A(t, i) e^{(j\omega_i t + \phi_i)}, \quad (1)$$

where $A(t,i)$ is a term defined by carrier modulation and $e^{(j\omega_i t + \phi_i)}$ describes a frequency location of a single carrier signal within a multicarrier band, and the phase offset between them. i represents the i th carrier within the multi-carrier band.

The aim is to minimise the peak-to-mean ratio (PAR) of the transmitted signal. The

5 PAR may be defined as follows:

$$PAR = \sqrt{\frac{\max(|y(t)|^2)}{\text{mean}(|y(t)|^2)}}$$

As discussed in the background to the invention, it is important to minimize the PAR without affecting certain other transmission requirements, namely the frequency requirements of a carrier, the peak amplitude EVM of the carrier, and
10 the RMS EVM of the carrier.

The frequency requirements of a transmitted carrier primarily require that the error signal must be located in the same frequency bands as the actual signal is located. This is because the error signal is part of the transmitted signal and it must fulfill the transmitter requirements.

15 According to the GSM (Global System for Mobile communications) specifications, the maximum peak EVM value must be no more than 22% greater than the average of peak values, measured from 200 bursts.

The requirements for the RMS EVM under normal operating conditions, and without the effect of passive combiners, is 7.0 %.

20 By checking the signal model defined in equation (1), it can be seen that there are effectively three different options for reducing the PAR of the output signal. In a first option, the terms $A(t,i)$ can be modified so that the PAR is minimised. This option can be considered as "clipping", as the modification of the terms $A(t,i)$ creates an amplitude error (EVM) in the output signal. In a second option, the
25 frequency ω_i terms of each carrier can be adjusted. However this causes a frequency error in the transmitted signal, and as such the ability to modify this term is limited by the system specifications. A third option is to adjust the phase offset ϕ_i

of each carrier. If such adjustment is done on a burst basis, it does not cause any error in the transmitted signal.

The second option is not a practical option for minimizing the PAR, due to the introduction of a frequency error. The first and third options do, however, offer alternatives for minimizing the PAR. The third option may be preferably considered as an alternative or supporting option for clipping algorithms.

An optimal clipping without any constraints (for the system parameters: frequency response, peak EVM, RMS EVM) can be written as a solution to an optimisation problem, namely:

$$J = \min_y (|r-y|^2) + \lambda(|y| \leq A) \quad (2)$$

Where J is the clipping function, r is a reference signal, y is a created output signal from the clipper, A describes the amplitude limit, and λ is the Lagrange multiplier. It can be seen that the optimal clipper for the signal envelope to achieve this function is a hard-clipper, which limits the amplitude of the complex envelope of the baseband signal.

A "real" clipper has additional constraints which have to be fulfilled. These constraints, as discussed above, include the frequency spectrum constraints and the peak EVM constraints, and may include the RMS EVM constraints. As these additional constraints must degrade the theoretical achievable performance of the clipper compared to the results presented by equation (2) above, the real clipper inevitably provides a worse performance than the idealized solution of equation (2).

In order to consider more fully what may be an optimal hard clipper implementation for real constraints, the cost function of equation (2) is modified to give a cost function which is approximated by the following function:

$$J = \min_y (|r-y|^2) + \lambda(|y| \leq A) + \sum p_i((r-y)^H P(r-y) \leq b_i) + \sum \xi_i(|r-y| \leq p), \quad (3)$$

where J is the clipping function, the term $\sum p_i((r-y)^H P(r-y) \leq b_i)$ defines the frequency spectrum constraints for each sub-band separately, and the last term defines the peak EVM constraints. Equation (3) thus represents the function of

equation (2) modified to take into account the frequency spectrum and peak EVM constraints.

The foregoing analysis sets out that a "hard-clipper" implementation provides an optimum solution, if there are no additional constraints on the system. If there are additional constraints, then the optimum solution of the "hard-clipper" cannot be achieved.

The cost function of equation (3) is only an approximation of the real constraints, and is used here to show the properties of a 'good clipper'.

The solution to the cost function of equation (3) may be found using Kuhn-Tucker conditions, but this leads to a fairly complex clipping algorithm. It is therefore not proposed to use Kuhn-Tucker conditions. Instead, the impact of the added constraints, frequency spectrum and peak EVM (and RMS EVM), to the properties of the error signal e are considered. In order to consider the error signal, it is necessary merely to consider the characteristics of such signal, rather than its mathematical construction.

As discussed above, the frequency spectrum (domain) requirements mainly require that the error signal must be located in the same frequency bands as the actual signal is located. If the frequency constraints of the cost function J in equation (3) are considered, it is known from the Kuhn-Tucker conditions that the function is minimised when each constraint is either 0 or b_i , depending on the signal characteristics. As the constraints are relatively tight, it is very probable that the optimum solution is found when $\sum (\rho_i(\mathbf{r}-\mathbf{y})^H \mathbf{P}(\mathbf{r}-\mathbf{y})) = b_i$, rather than 0. On the other hand this means that the 'optimal' error signal needs to be as wideband a signal as is possible. Considering this same issue from a more practical point of view, the same conclusion can be reached: the wider the allowed error signal bandwidth is, the more peak-heavy is the impulse response of the error signal and therefore the less additional EVM is caused due to frequency requirements compared to the hard-clipper in the case of individual peaks.

In respect of the peak EVM as stated hereinabove according to the GSM specifications the maximum peak EVM value is 22%, and it is measured as an average of peak values from at least 200 bursts. The term used in the cost function of equation (3) gives an absolute limit for the peak error, and therefore the cost function is not strictly related to the GSM standard.

In accordance with the present invention, there is provided a technique in which a clipping signal is formed by creating a hard clipper residual signal, while simultaneously obtaining a wanted frequency response. Fitting may be achieved in the sense of Least Squares.

Thus, a least squares clipper attempts to imitate the behaviour of the ideal hard clipper. In practise, the purpose is to generate a signal such that the formed composite signal resembles the hard clipper type residual signal y_T as much as possible, as discussed hereinbelow.

The invention is further discussed in detail hereinbelow with reference to the Figures, which illustrate example implemenatations for the invention.

Figure 1 illustrates a block diagram of an exemplary implementation in accordance with the present invention. The implementation includes an impulse generator 102, a delay element 104, and a set of complex filters 106a to 106d. The impulse generator 102 and the delay element 104 each receive the multi-carrier signal to be transmitted on line 300. The outputs of each of the complex filters on lines 122a to 122d are summed in summers 124a to 124c. The summed output is added to the output of the delay element on line 120 by summer 126. The output of the summer 126 on line 128 provides an input to a power amplifier (not shown).

The arrangement of Figure 1 may be considered overall to be a 'PAR minimiser apparatus', and is effectively a pre-power amplifier stage. A multi-carrier signal to be transmitted is present on line 300.

The purpose of the impulse generator 102 and the complex filters 106 is to add an error signal to the multicarrier signal in line 300, such that the output PAR is minimised. The error signal, on line 123 at the output of summer 124a, is input to

the second input of the mixer 126 where it is added to a delayed version of the multicarrier signal at the first input of the mixer 126 on line 120. The delay block 104 merely compensates for the processing delays in the impulse generator and the complex filters, which together may be considered an error block 101.

- 5 The added error signal on line 123 must fulfil the above-described frequency constraints and the peak and RVS-EVM constraints. As discussed hereinabove, the "hard-clipper" provides an idealised result. Thus the signal on line 123 should approximate as closely as possible while fulfilling the additional constraints.

Referring to Figure 3, there is illustrated an example implementation of the error
10 impulse generator block 102 of Figure 1. The signal on line 300 provides an input to a block 302 which generates a single residual signal on line 304. The residual signal on line 304 is the difference between the original transmitted signal on line 300 and a "hard-clipped signal". Thus it represents the error associated with hard-clipping.

- 15 The hard-clipped signal itself may be generated by limiting the maximum amplitude of the signal to be transmitted on line 300 to a predefined limit. The derivation of such a hard-clipped signal will be within the scope of one skilled in the art. The residual signal is then obtained by simply subtracting the hard-clipped signal from the original signal. The 302 of Figure 3 thus includes a hard-clipper and a
20 subtractor which operate on the signal on line 300 to produce the residual signal on line 304

The thus generated residual signal does not fulfill the frequency constraints (or other constraints) as discussed hereinabove. In order to fulfill the frequency constraints, a least squares technique is utilized in order to search a signal which
25 close as possible to the residual signal whilst fulfilling the frequency constraints.

The residual signal y_T on line 304 forms an input to a least-squares fitting functional block 306. The least-squares fitting functional block 306 generates a series of outputs on lines 308a to 308d. The outputs of the least-squares fitting block on lines 308a to 308d are a set of generated impulse vectors

$x_1, \dots, x_{\text{no_of_carriers}}$. The number of impulse vectors corresponds to the number of carriers in the multi-carrier signal, in the example shown four.

The least square fitting of the block 306 of Figure 3 is used to find the best fit for the "hard-clipper" residual signal for each carrier such that the frequency constraints for each carrier frequency are fulfilled. The fitting criteria, in the described embodiments, is to minimise the squared difference (i.e. a least-squares optimisation).

The impulse vectors x_1, \dots, x_4 on lines 308a to 308d are thus preferably generated through the complex filters 106a to 106d, identified as g_1, \dots, g_4 respectively. The clipper filters g_i are specially designed for each carrier, so as each carrier has the same frequency characteristics as the transmitted signal. In practice the complex filters' coefficients are formed by up-converting the impulse of the transmitter's filter to each carrier's frequency. The outputs of the filters 106a to 106d are provided on lines 122a to 122d respectively.

Figure 2 shows an example implementation of one of the complex filters in Figure 1, for example the filter 106a. Each filter includes a transmitter filter 202, the input of which is formed by the input to the filter on line 308a, and the output of which on line 206 forms an input to a mixer 204. The mixer 204 serves to up-convert the signal on line 206 based on an up-convert frequency on line 208. The output of the mixer 204 forms the output of the filter on line 122a.

A mathematical analysis of the implementation shown in Figures 1 to 3 is given below.

The principle is to minimise a cost function which represents the squared distance between the "hard-clipper" residual signal and the output from the least-squares fitting block. That is, the output of the least-squares fitting block should approximate as closely as possible the "hard-clipper" residual signal. Thus by trying to minimize the cost function:

$$J = |y_T - Gx|^2,$$

where $G = (G_1 G_2 \dots G_{nro_of_carriers})$, G_i is a convolution matrix, whose columns are defined by g_i and $x = (x_1 x_2 \dots x_{nro_of_carriers})^T$ is a vector of impulse vectors, the following is obtained:

$$x_{min} = (G^H G)^{-1} G^H y_T.$$

5 It is known that $G_i^H G_j = \bar{0}$ (zero matrix), when $i \neq j$, hence

$$x_i = (G_i^H G_i)^{-1} G_i y_T.$$

A solution is described hereibelow for solving the matrix equation above. This solution is too complex for practical implementations, but is presented for illustration purposes. This solution shows how you may resolve the matrices in
10 the result for x given above.

Figure 4 illustrates a modification to the arrangements of Figures 1 and 3 in which the complex filters 106 are replaced by complex filters 404.

The hard clipper type residual signal is generated and multiplied by a projection matrix $G_i(G_i^H G_i)^{-1} G_i^H$ of each carrier's spanned signal space. Signals are summed
15 up, and deducted from the transmitted signal as described before. This is represented by Figure 4. The hard clipper type residual signal is generated by block 400, which corresponds to the block 300 of Figure 3, from the multicarrier signal. The hard clipper type residual signal forms an input to each of a plurality of complex filters 404a to 404d where the multiplication by the projection matrix takes
20 place. The output of the filters 404a to 404d are summed in summers 406a to 406c, and subsequently summed by summer 408, to generate a multi-carrier signal on line 410 which drives a power amplifier.

The matrix solution can be simplified by filters as illustrated in Figure 5. Figure 5 represents a practical solution for the implementation of the complex filters 404a to
25 404d of Figure 4. Figure 5 illustrates an approximation of the filters of Figure 4. Even when the clipper become feasible it impairs the results slightly.

As shown in Figure 5, each filter 404a to 404d may include a matrix function 502a to 502d, a sampling function 504a to 504d, a filter 506a to 506d, and an interpolation function 508a to 508d. The residual signal is operated with the transpose of a complex conjugation matrix (i.e. a matched filter) G , represented by
5 blocks 502a to 502d. In these solutions the matrix inversion $(G^H G)^{-1}$ is replaced by the ISI removal filter $r_{x,y}$, represented by blocks 506a to 506d.

The present invention has been described herein by way of a reference to particular examples. The invention is not limited to such examples, or aspects thereof. The scope of the present invention is defined by the appended claims.

Claims

1. A method of reducing the peak-to-mean ratio of a multi-carrier signal comprising the steps of:
 generating a residual signal from the multicarrier signal, the residual signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal;
 applying a least squares function to the residual signal for each carrier of the multi-carrier signal, thereby generating a minimised residual signal for each carrier; and
 combining the minimised residual signals and the multicarrier signal.
2. A method according to claim 1 further comprising the step of, prior to the step of combining the minimised residual signals, of filtering each minimised residual signal.
3. A method according to claim 1 or claim 2 further comprising the step of delaying the multicarrier signal, wherein the delayed multicarrier signal is combined with the minimised residual signals.
4. A method according to any preceding claim in which the step of generating the residual signal includes a step of clipping the multicarrier signal to a predetermined level to thereby generate the hard-clipped multicarrier signal.
5. A method according to any one of claims 2 to 4 wherein the step of filtering comprises complex filtering.
6. A method according to claim 5 in which step of filtering comprises a step of multiplying the residual signal by a projection matrix of each carrier's spanned signal space.
7. A method according to claim 5 in which the step of filtering includes the steps of applying to the residual signal, for each carrier, a matrix function, a sampling function, a filtering function and an interpolation function.

8. A method according to any preceding claim in a mobile communication system.
9. Apparatus for reducing the peak-to-mean ratio of a multi-carrier signal including:

means for generating a residual signal from the multicarrier signal, the residual
 5 signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal;

means for applying a least squares function to the residual signal for each carrier of the multi-carrier signal, thereby generating a minimised residual signal for each carrier; and

10 means for combining the minimised residual signals and the multicarrier signal.

10. Apparatus according to claim 9 further comprising means for filtering each minimised residual signal prior to combining.

11. Apparatus according to claim 9 or claim 10 further comprising means for
 15 delaying the multicarrier signal, wherein the delayed multicarrier signal is combined with the minimised residual signals.

12. Apparatus according to any one of claims 9 to 12 in which the means for generating the residual signal includes means for clipping the multicarrier signal to a predetermined level to thereby generate the hard-clipped multicarrier signal.

20 13. Apparatus according to any one of claims 10 to 12 wherein the means for filtering comprises a complex filter.

14. Apparatus according to claim 13 in which the means for filtering comprises means for multiplying the residual signal by a projection matrix of each carrier's spanned signal space.

25 15. Apparatus according to claim 13 in which the step of filtering includes means for applying to the residual signal, for each carrier, a matrix function, a sampling function, a filtering function and an interpolation function.

16. A mobile communication system including a transmitter apparatus adapted for reducing the peak-to-mean ratio of a multi-carrier signal including:

means for generating a residual signal from the multicarrier signal, the residual signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal;

means for applying a least squares function to the residual signal for each carrier of the multi-carrier signal, thereby generating a minimised residual signal for each carrier; and

means for combining the minimised residual signals and the multicarrier signal.

17. A GSM EDGE mobile communication system according to claim 16.

Abstract

There is disclosed a method of reducing the peak-to-mean ratio of a multi-carrier signal comprising the steps of: generating a residual signal from the multicarrier signal, the residual signal representing the difference between the multicarrier signal and a hard-clipped multicarrier signal; applying a least squares function to the residual signal for each carrier of the multi-carrier signal, thereby generating a minimised residual signal for each carrier; and combining the minimised residual signals and the multicarrier signal.

[Figure 1]

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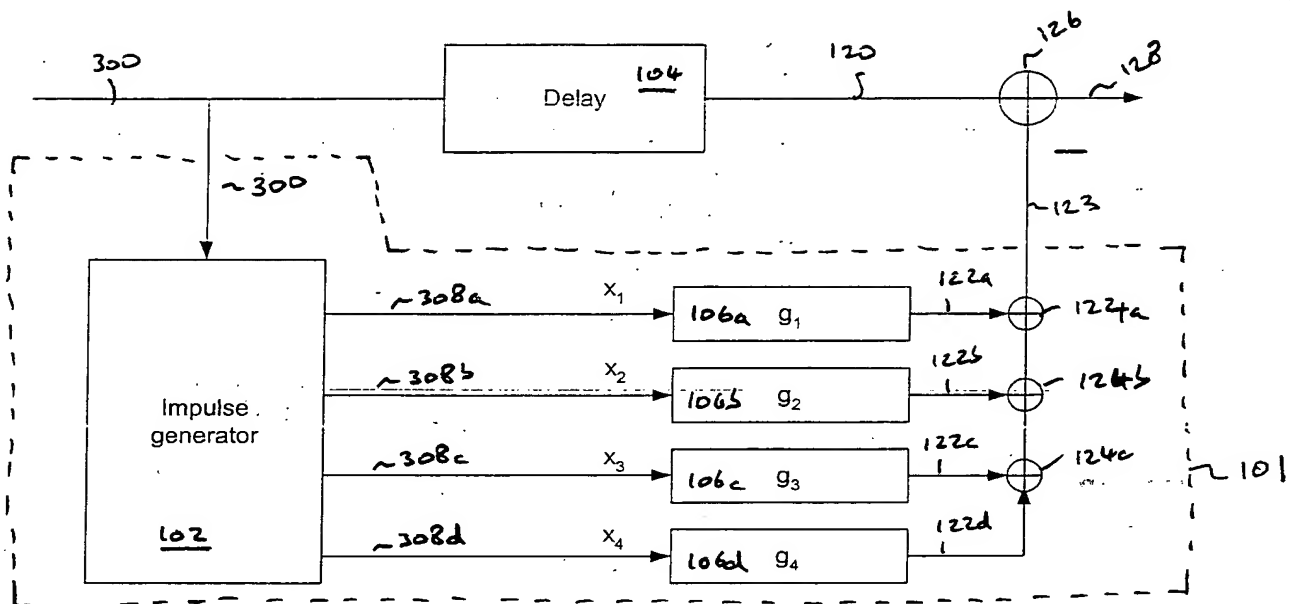


Figure 1

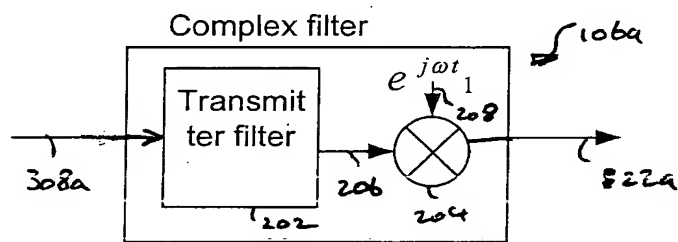


Figure 2

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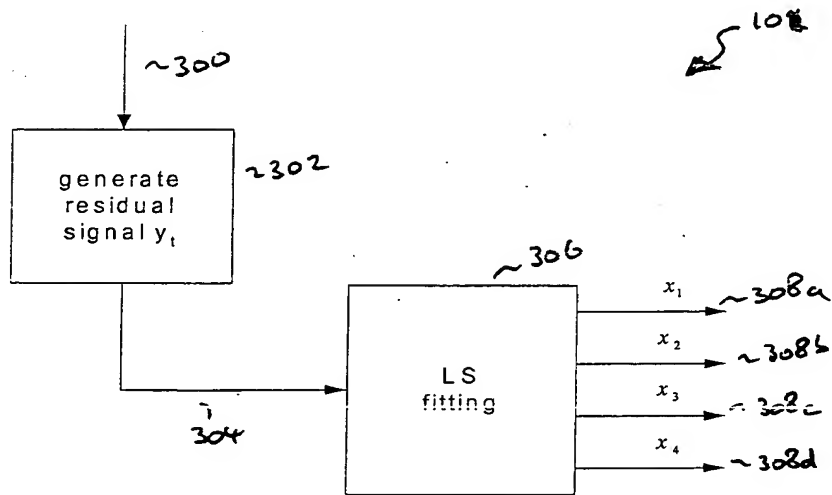


Figure 3

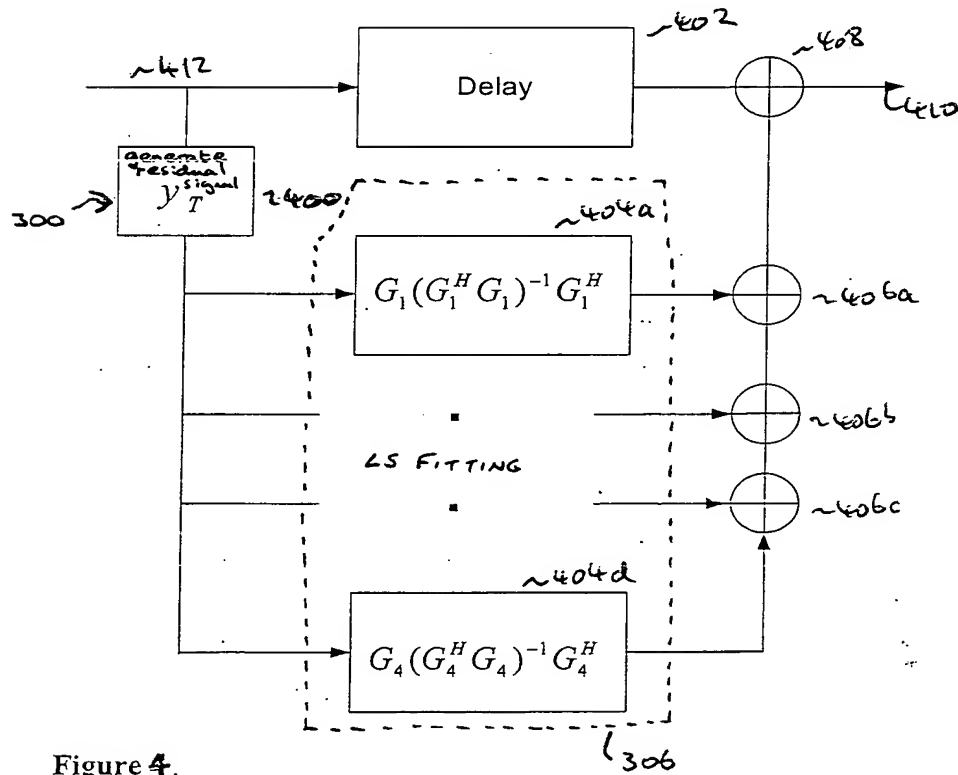


Figure 4.

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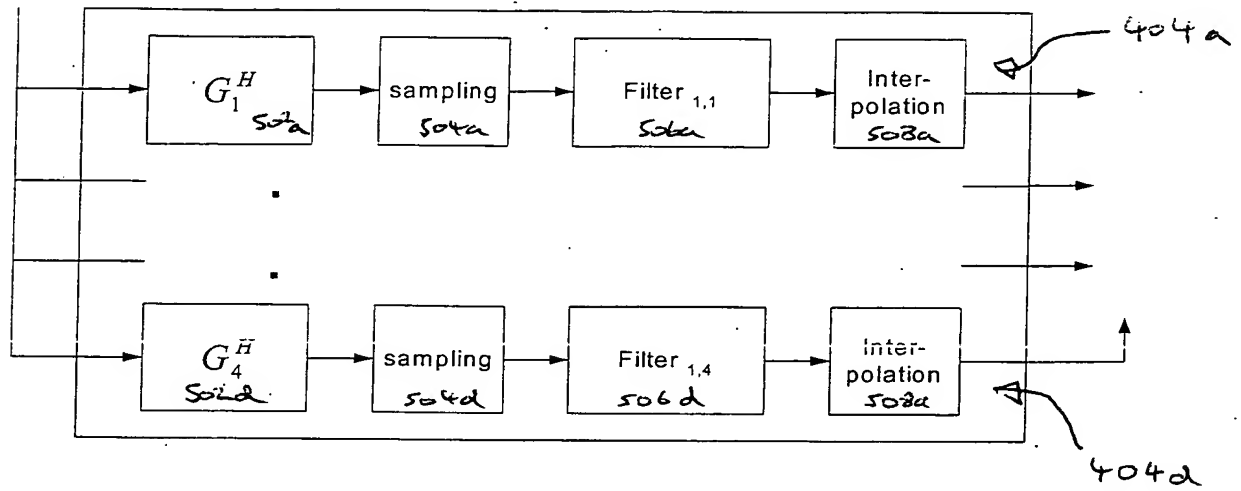


Figure 5

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